Fourier Transform Inelastic Electron Tunneling Spectroscopy and STM

Alexander V. Balatsky and Jian-Xin Zhu, T-11

Recent advances in scanning probes, such as Scanning Tunneling Spectroscopy (STM) have made it possible to investigate the properties of correlated electron systems at extreme spatial resolution. One of the spectroscopies that is used to investigate electronic properties is Inelastic Tunneling Spectroscopy (IETS), which allows us to measure the characteristic energies of local and extended modes that scatter electrons in a sample.

It is known that the inelastic scattering processes produce a feature in tunneling characteristics, dI/dV. These features point to the characteristic excitation energies that are involved in inelastic scattering. Thus, by observing these features in IETS one can perform spectroscopy of the degrees of freedom that are responsible for inelastic scattering of the electrons.

By combining IETS with STM one can investigate the properties of the inelastic scattering at extreme spatial resolution. The IETS scanning tunneling microscopy (IETS-STM) for example, allows us to measure the local vibrational modes of atoms or molecules on a surface.

We propose to extend the use of Fourier Transform STM to address the inelastic processes and detect characteristic energy and momenta of the scattering modes that would produce IETS features. We call the proposed technique Inelastic Electron Tunneling Spectroscopy Fourier Transform STM (IETS FT STM).

First, we outline the conventional FT STM approach, where one deals with static elastic scattering. Consider, for example, simple metal. Any defect on the metal surface is known to produce standing electronic waves. These waves are called Friedel oscillations and are well known in the literature. Encoded in these oscillations is information about the Fermi wave vector of electrons kF. Fourier transform of the standing wave would produce, in a simplest case, a circle in the k-space with the radius 2kF. Straight Fourier transform would reveal the Fermi surface momentum of a metal, as shown in Fig.1.

The standing wave seen in these experiments is a result of elastic scattering, with no energy transferred between defects and incidental electrons. One can ask a question on how the "Friedel oscillations" will look when the scattering will be inelastic.

We took the next step and combined the IETS with FT STM. The proposal is to start with measuring the inelastic tunneling features at each point of a pixelized field of view seen in STM. Central quantity for this would be d2I/dV2 measured in the IETS experiment, at each point r. Then one performs the Fourier transform on r. The resulting quantity is d2I/dV2 as a function of k and energy. This quantity has encoded in it the energy and momentum information of the inelastic scatterers. We suggest that we might extract those from FT d2I/dV2, as seen in Fig. 2

Without going into technical details, we have done some model calculations that show the feasibility of this approach. The ultimate validation of this approach would only be possible using real experimental data. We are collaborating with the STM group at Cornell University to apply FT IETS STM approach to the high temperature superconductors.

For more information contact Alexander Balatsky at avb@lanl.gov.

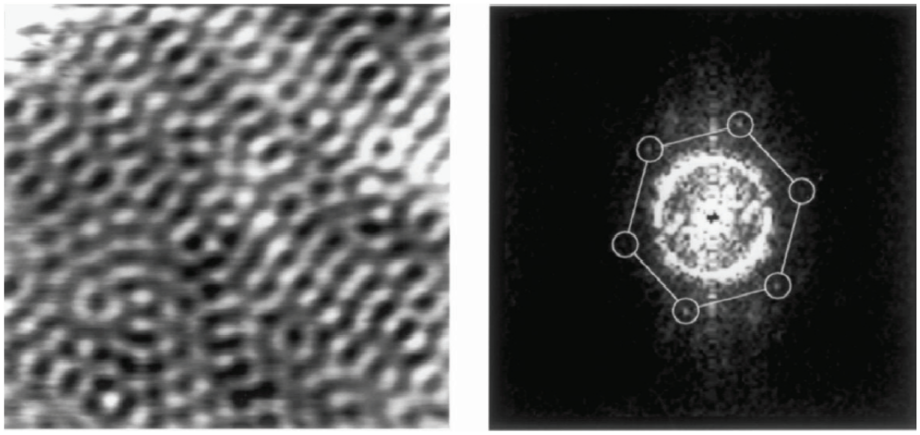

Fig. 1.
Example of FT-STM: a) Be (001) surface, as seen by STM, with the standing waves (Friedel oscillations) produced by defects, b) Fourier transform of (a) reveals a cut through the Fermi surface corresponding to the surface states.

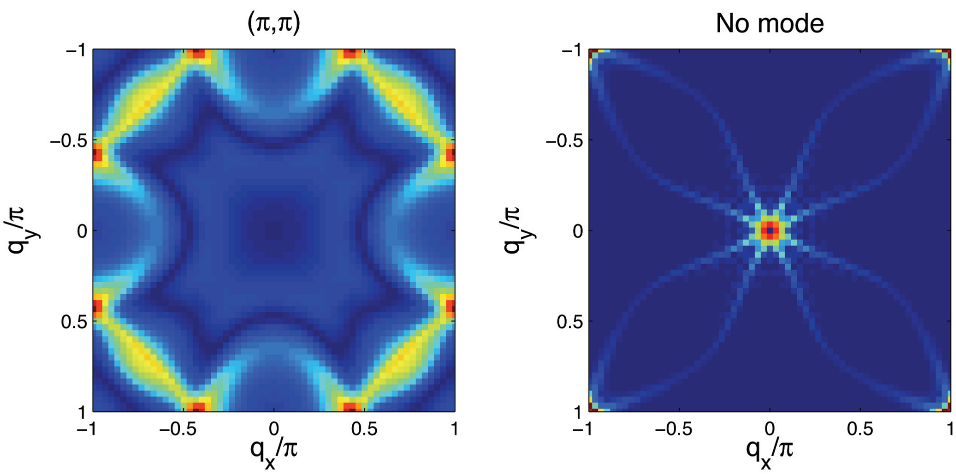

Fig. 2.
The Fourier spectral weight of the energy derivative of the LDOS at E taken at the superconducting gap plus the energy of the mode for a d-wave superconductor with the electronic coupling to the spin resonance modes. For comparison, the quantity is also shown for the case of no mode coupling (g = 0).